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CHOLESTERIC LIQUID CRYSTAL DISPLAY SYSTEM

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CHOLESTERIC LIQUID CRYSTAL DISPLAY SYSTEM

FIELD OF THE INVENTION

The present invention relates to a display system having a cholesteric liquid crystal that changes optical states in response to heat, light and electrical field.

BACKGROUND OF THE INVENTION

Cholesteric liquid crystals have the property of maintaining several different optical states in the absence of electrical field. Additionally, cholesteric liquid crystals can change optical states in response to applied electrical and/or thermal fields. Those properties make them useful in the development of field stable, re-writable displays.

US 3,401,262 issued September 10, 1968 to Fergason et al. discloses a cathode ray tube to apply light to a screen. The screen has a photoconductive layer that is excited by an electrical field applied by fine leads across the photoconductive layer. The screen has a layer of a temperature sensitive cholesteric material that changes reflective wavelength with slight changes in temperature, and changes hue in heated areas. Light from the cathode ray tube strikes the photoconductor layer, creating heat that can be used to selectively change the color of the sheet of cholesteric material. The system uses a complex cathode ray tube and a photoconductor layer and ceases to present an image in the absence of an electrical field.

US 3,578,844 issued May 18, 1971 to Churchill discloses a sheet of gelatin encapsulated cholesteric material without a photosensitive layer. The sheet is put into a first reflective state by heating. Portions of the sheet are written into a black (clear) state by the application of DC fields. The sheet is heated to reset the display. The encapsulated material in the sheet retained written information without fade at ambient conditions for eight weeks.

US 3,789,225 issued January 29, 1974 to Leder discloses a glassy cholesteric liquid crystal between glass plates. Glassy liquid crystal materials are

solidified liquid crystals in an orderly state at ambient temperatures. They are not responsive to electrical fields in the glassy state. The apparatus writes the sheet to an initial state by heating the material above the isotropic (liquid) transition point. As the material is cooled, a high intensity xenon flash lamp is used to disturb the material so that flash disturbed areas solidify into a state different than areas not receiving flash energy. The imaging system requires that the materials be raised to a high temperature, and cooled at a fast rate in the presence of selective high intensity flash light. No electrical fields are applied to the media.

Conventional, non glassy liquid crystals have the property of being electrically driven between a planar state reflecting a specific visible wavelength of light and a light scattering focal conic state at ambient temperatures. Chiral nematic liquid crystals, also known as cholesteric liquid crystals have the capacity of maintaining one of multiple given states in the absence of an electric field. US 5,437,811 issued August 1, 1995 to Doane et al. discloses a light modulating cell having a polymer dispersed chiral nematic liquid crystal. The chiral nematic liquid crystal has the property of being driven between a planar state reflecting a specific visible wavelength of light and a weakly light scattering focal conic state. Chiral nematic liquid crystals, also known as cholesteric liquid crystals, have the capacity of maintaining one of multiple given states in the absence of an electric field. The Doane et al. patent discloses the use of only electrical fields to change the optical state of cholesteric liquid crystals. The technology writes image data line sequentially. Sequentially writing data lines is slow compared to writing all pixels at once and requires electrical drivers on each column and row line.

US 6,268,840 issued August 1, 1995 to Huang discloses phased drive signals applied to a cholesteric display incorporating multiple voltage levels applied to the material in a sequence. A first preparation phase forces cholesteric liquid crystal into the homeotropic state. In the selection phase, sequential lines of data have the one of two voltages applied to each pixel. A lower voltage applies a moderate voltage level to the liquid crystal to unwritten lines and for a period after all lines are written. The process is applicable to sequentially writing lines of

cholesteric material using electrical fields, however the lines must be electrically written sequentially.

Yamamoto et al. in A Novel Photoaddressable Electronic Paper Utilizing Cholesteric LC Microcapsules and Organic Photoconductor, SID 2001 DIGEST, pp. 362-365, create an electronic paper having a photoconductive layer and a polymer encapsulated cholesteric liquid crystal that is field responsive at ambient temperatures. A high electrical field is applied across both layers, and the photoconductive layer provides a bias voltage in the presence of light. The high and low field states across the material write cholesteric material into different optical states.

Prior art light sensitive sheets have required expensive and complex photosensitive layers for operation. Electrical drive systems must write data sequentially, requiring complex electronic drives. Glassy liquid crystals change state with the application of large amounts of heat and no electrical field. There is a need therefore for a light written sheet that could have image data written simultaneously without a photosensitive layer at low temperatures.

SUMMARY OF THE INVENTION

The need is met according to the present invention by providing a method of writing an image on a liquid crystal display of the type having a layer of cholesteric liquid crystal material disposed between a pair of unpatterned conductors and a light absorbing layer for forming an image wise thermal pattern in response to an image wise pattern of light that includes applying a first voltage to the conductors; applying a second voltage different from the first voltage to the conductors after applying the first voltage, wherein the first and second voltages are non-zero; and exposing the liquid crystal display to the image wise pattern of light.

ADVANTAGES

The present invention has the advantage that it provides a method for writing high quality images using conventional liquid crystal display having poor modulation properties in the combined visible and infrared spectrum. The writing process is fast, and improves image quality over displays written only electrically.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a partial cross sectional view of a prior art display that can be written in accordance with the present invention;

Fig. 2 is a schematic side view of chiral nematic material in a planar and focal-conic state responding to incident light useful in describing the operation of the display of Fig. 1;

Fig. 3 is schematic side view of apparatus used to write an image on a display in accordance with the present invention;

Fig. 4 is a plot of the response of the display of Fig. 1, originally in the planar state, to constant flash lamp energy and various voltages;

Fig. 5 is a plot of the response of the display of Fig. 1, originally in the focal-conic state, to constant flash lamp energy and various voltages;

Fig. 6 is an electrical schematic diagram for a display writer useful in practicing the method of the present invention;

Fig. 7 is a side section view of the writer connected to a display used in practicing the method of the present invention;

Fig. 8 is a plot of the spectral output of a prior art commercial flash unit;

Fig. 9 is a plot of the transmission for visible and infrared wavelengths of a super twisted nematic (STN) display used in the writing apparatus shown in Fig. 7;

Fig. 10 is a diagram of signals applied to change the state of display in accordance with Figs. 4 and 5;

Fig. 11A is a waveform diagram useful in describing one embodiment of the writing method of the present invention using a two phase drive scheme;

Fig. 11B is a waveform diagram useful in describing one embodiment of the writing method of the present invention using a bipolar waveform having variable amplitude and duty cycle;

Fig. 12A is a waveform useful in describing an alternative embodiment of the writing method of the present invention using a three phase drive scheme;

Fig. 12B is a waveform useful in describing an alternative embodiment of the writing method of the present invention using a three phase drive scheme wherein the third voltage is zero;

Fig. 13 is a representation of states of liquid crystals written in accordance with the method shown in Fig. 12B;

Fig. 14 is a waveform useful in describing an alternative embodiment of the writing method of the present invention using a four phase drive scheme;

Fig. 15 is a waveform useful in describing an alternative embodiment of the writing method of the present invention using a five phase drive scheme; and

Fig. 16 is a spectra plot of the reflectance of a display written in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 is a partial cross sectional view of a display which can be written in accordance with the present invention. The display **10** includes a display substrate **15**, such as a thin transparent polymeric material, for example, Kodak Estar film base formed of polyester plastic that has a thickness of between 20 and 200 (preferably 125 microns). Other polymers, such as transparent polycarbonate, can also be used.

A first transparent conductor **20** is formed on display substrate **15**. First transparent conductor **20** can be tin oxide, indium tin oxide (ITO), or polythiophene, with ITO being the preferred material. Typically the material of first transparent conductor **20** is sputtered or coated as a layer over display substrate **15** having a resistance of less than 1000 ohms per square.

Cholesteric layer **30** overlays a first portion of first transparent conductor **20**. A portion of cholesteric layer **30** is removed or is uncoated to create exposed first conductor **20'** to permit electrical contact. Cholesteric layer **30** contains cholesteric liquid crystal material, such as those disclosed in US 5,695,682 issued December 9, 1997 to Doane et al. Application of electrical fields of various intensity and duration can be employed to drive a chiral nematic material (cholesteric) into a reflective state, to a substantially transparent state, or an intermediate state. These materials have the advantage of having first and second optical states that are both stable in the absence of an electrical field. The materials can maintain a given optical state indefinitely after the field is removed. Cholesteric liquid crystal materials can be Merck BL112, BL118 or BL126, available from E.M. Industries of Hawthorne, N.Y.

Cholesteric layer **30** is E.M. Industries' cholesteric material BL-118 dispersed in deionized photographic gelatin. The liquid crystal material is mixed at 8% concentration in a 5% gelatin aqueous solution. The liquid crystal material is dispersed to create an emulsion having 8-10 micron diameter domains of the liquid crystal in aqueous suspension. The domains can be formed using the limited coalescence technique described in US Patent 6,423,368 issued July 23, 2002 to Stephenson et al. The emulsion is coated on a polyester display substrate over the first transparent conductor(s) and dried to provide an approximately 9-micron thick polymer dispersed cholesteric coating. Other organic binders such as polyvinyl alcohol (PVA) or polyethylene oxide (PEO) can be used in place of the gelatin. Such emulsions are machine coatable using coating equipment of the type employed in the manufacture of photographic films. A thin layer of gelatin can be applied over the first transparent conductor **20** to provide an insulator prior to

applying cholesteric layer **30** as disclosed copending USSN 09/915,441 filed July 26, 2001 by Stephenson et al.

Fig. 2 is a schematic side sectional view of a chiral nematic material in a planar and focal conic state responding to incident light. In the figure on the left, after a high voltage field has been applied and quickly switched to zero potential, the liquid crystal molecules become planar liquid crystal **72**, which reflect portions of incident light **60** as reflected light **62**. In the figure on the right side of Fig. 2, upon application of a lower voltage field, the molecules of the chiral nematic material break into weakly forward scattering cells known as focal conic liquid crystal **74**. Increasing the time duration of a low voltage pulse progressively drives the molecules that were originally reflective planar liquid crystal **72** towards a fully evolved and weakly light scattering focal conic liquid crystal **74**.

A light absorbing dark layer **35** (herein called a dark layer because it absorbs visible and IR light, but it can absorb only a portion of the visible spectrum and have a colored appearance) is positioned on the side opposing the incident light **60**. Dark layer **35** can be a thin layer of light absorbing, sub-micron carbon in a gel binder as disclosed in US 6,639,637 issued June 26, 2003 to Stephenson. As fully evolved focal conic liquid crystal **74**, the cholesteric liquid crystal is forward light scattering and incident light **60** passing through dark layer **35** and is absorbed to create a black image. Progressive evolution towards the focal conic state causes a viewer to perceive reflected light **62** that is reduced to black as the cholesteric material changes from reflective planar liquid crystal **72** to a fully evolved light scattering focal conic liquid crystal **74**. When the field is removed, cholesteric layer **30** maintains a given optical state indefinitely. The states are more fully discussed in US 5,437,811, referenced above.

Returning to Fig. 1, dark layer **35** is disposed between second conductor **40** and cholesteric layer **30** to improve contrast. A second conductor **40** overlays cholesteric layer **30**. Second conductor **40** has sufficient conductivity to provide an electric field between the first transparent conductor **20** and second conductor **40** strong enough to change the optical state of the cholesteric material

in cholesteric layer **30**. Second conductor **40** can be formed, for example, by the well known technique of vacuum deposition for forming a layer of conductive material such as aluminum, tin, silver, platinum, carbon, tungsten, molybdenum, tin or indium or combinations thereof. Second conductor **40** can also be formed by screen printing a conductive ink such as Electrodag 423SS screen printable electrical conductive material from Acheson Corporation. Such screen printable conductive materials comprise finely divided graphite particles in a thermoplastic resin. Screen printing is preferred to minimize the cost of manufacturing the display. A first conductor cover **22** can be similarly printed over first transparent conductor **20**. First conductor cover **22** protects first transparent conductor **20** from abrasion.

The use of a flexible support for display substrate **15**, first transparent conductor **20**, machine coated dark layer **35**, and cholesteric layer **30**; and printed second conductor **40**, and first conductor cover **22** permits the fabrication of a low cost flexible display. Small flexible displays can be used as re-writable tags for inexpensive, limited rewrite applications.

Fig. 3 is schematic side view of an experimental setup used to write a display in accordance with the present invention. In Fig. 3, a display **10** was positioned so that a conventional xenon flash **52** exposed portions of display **10** through mask **54**. In the experiment, flash **52** was a Vivitar model 285HV professional flash lamp and mask **54** was a sheet of Dupont Mylar transparency with an electrophotographic printed image. The output of flash **52** was adjusted to imprint an image on display **10** if the cholesteric material was initially either planar liquid crystal **72** or focal-conic liquid crystal **74**.

Electrodes **50** were applied to first conductor cover **22** and second conductor **40**. A constant electrical field was applied across electrodes **50**, and flash imprinted images on display **10** were erased. Display **10** could be imprinted and erased multiple times without damage to display **10**. Display **10** was positioned so that the black second conductor **40** faced flash **52** and mask **54**. Flash **52** could be adjusted so that images were imprinted through opaque second

conductor **40**. The images can be electrically erased using a field across electrodes **50**. From these experiments, it was concluded that the printing process occurs due to the electric field applied across first and second conductors and thermal energy being applied to second conductor **40** through either side of display **10**. A heat pulse of correct power and duration provides a thermal flux effect that can write cholesteric material into either the planar or focal conic state or combination of the two states. These experiments demonstrated the utility of masked high intensity light to thermally print and reprint images on polymer dispersed cholesteric liquid crystals. The method and materials permit multiple erasure and writing cycles. Furthermore, the structure of display **10** is flexible and low cost.

Experiments were performed to determine the response of display **10** to the application of constant electrical fields during the thermal heat pulses from flash **52**. In a first experiment, display **10** was electrically written into the planar state using a high voltage pulse. The output of flash **52** was set so initially planar liquid crystal was selectively written into the focal conic state in unmasked areas. The display was repeatedly reset to the planar state, and written using a series of voltages.

To increase the lifetime of liquid crystal displays, it is known to apply bipolar drive voltages to the electrodes of the display to reduce charge build up at the surfaces of the electrodes. It is to be understood that the term voltage as used herein may refer to a root mean square (RMS) voltage that is generated by a bipolar waveform. The value of the RMS voltage is determined by the amplitude and duty cycle of the bipolar voltage waveform applied to the electrodes of the display. Different combinations of amplitude and duty cycle may be used to generate any given RMS voltage. As used herein, the term voltage may refer to a zero or non-zero RMS voltage.

Fig. 4 is a plot of the response of the display of Fig. 1, originally in the planar state, at constant flash lamp energy and various voltages. For each test, the material was initialized into the planar state using a high voltage pulse. A constant test voltage was applied during a flash event. The resulting curve is

equivalent to the response curve found in the Doane et al. patent for electrically written cholesteric liquid crystal. The curve for the masked portion of the display (filled boxes) is the same as the response of a display in the absence of the thermal pulse provided by flash **52**. The curve for the unmasked (clear) portion of the display shows the response of the display in the presence of the heat pulse from the flash combined with a constant electrical field. At zero applied voltage and without a mask, planar material is written into the focal conic state and has a reflectance of about 7 percent. Applying a low voltage, such as **10** volts, improves the clarity of focal conic state from 7 percent to about 2 percent reflectance. It can be seen from Fig. 4 that applying a high voltage, such as 60 volts, can result in another pair of bistable states.

Fig. 5 is a plot of the response of the display of Fig. 1, originally in the focal conic state, at constant flash lamp energy and various voltages. Application of a low field again reduces the reflection of focal conic material from 7 percent to 2 percent. Only one pair of bistable states is possible in this system, again at 60 volts, which has a contrast ratio of about 13. Material initially in the focal conic state remains in the focal conic state at a medium level voltage. Energy from flash **52** causes initially focal-conic material to be driven into the planar state. Apparently, heat from flash **52** reduces the voltage required to drive cholesteric material into the planar state.

It was observed that at 60 volts of applied field, the final state of the material was defined by mask **54** if the material was initially in either the planar or focal conic state. The phenomenon eliminates the need to initially write the material into an initial state before flash writing an image. The single writing process, without an initialization step, provides a fast, parallel method of writing display **10**.

Fig. 6 is an electrical schematic for a display writer **90** useful in practicing the present invention. A power supply **91** provides power to a flash capacitor **92** and to the display drive **93**. A masking display **94** is disposed to selectively mask the output of flash **52**. Masking display **94** can be a simple

twisted nematic (TN) or super twisted nematic (STN) display of conventional design. Controller **95** supplies information to masking display **94**. Controller **95** applies writing voltage to electrodes **50** through display drive **93**, connected to display **10**. A trigger circuit **96** triggers flash **52** in conjunction with the application of a bipolar electrical field from display drive **93**. The flash energy is masked by masking display **94** to apply an image wise light pattern from flash **52** in conjunction with an applied field to write an image on display **10**.

Fig. 7 is a side section view of the writer **90** connected to the display **10**. Display **10** is attached to an object **80**, which has conductive adhesive contacts **82** attaching display **10** to object **80**. Writer **90** is connected to display **10** when electrodes **50** are pressed against contacts **82**. Sensors (not shown) of conventional design can be connected to controller **95** to signal that writer **90** is connected to display **10**. Switching means can activate controller **95** to write an image to display **10**. Writer **90** can be detached from display **10**, and used to write other displays **10**. Object **80** has attached information on display **10** that has been updated.

In an experiment, a dot matrix super twisted-nematic (STN) display, part number TM 13164 BCHG-1 from Tianma Microelectronics Corporation in China was placed over a display **10** which was built in accordance to the preferred embodiment. A Vivitar flash, already described, was adjusted so that light absorbing portions of the STN display masked the flash and transparent portions of the STN display passed flash light. The masking effect was sufficient to write areas of display **10** into the focal conic or planar states depending on the optical state of the masking display **94**. The flash unit was discharged through the STN display repeatedly with no observable harm to the structure of the STN display or display **10**. The experiment shows that it is possible to use simple, low-cost STN displays as masking display **94**.

Fig. 8 is a plot of the spectral output of the Vivitar flash unit. Xenon flash lamps in such flash units emit both visible (VIS) and infrared (IR) radiation. A significant portion of the light output is in the infrared (IR). Fig. 9 is

a plot of the transmission of the Tianma STN display for visible (VIS) and infrared (IR) wavelengths. The display has two polarization films, a first film to polarize light and a second film to selectively block light based on the polarization of light after it had passed through an electrically modulated liquid crystal layer. Plots are shown for the display in the transmissive state (T) and an opaque state (O). Transmission through the display was measured from 400 nanometers to 1100 nanometers for each of the two states. The display is designed for presentation of information in the visible spectrum, as a consequence, the design of the device passes 65% of most infrared radiation. The display blocks the majority of visible light, switching between about 18% transmission in the Transmissive mode (T) and about 4 percent in the opaque (O) visible light blocking mode, providing a 4:1 ratio in modulated visible light. The difference in transmitted and blocked energy between transmissive (T) state and opaque (O) state respectively is small when modulating light generated by a high intensity xenon flash lamp. The modulation capability is representative of transmissive liquid crystal displays with conventional liquid crystal materials and conventional polarizers. It is useful to find a method to operate the flash and apply an electrical field to create high contrast images in cholesteric material using conventional transmissive liquid crystal displays to modulate flash output.

Fig. 10 is a diagram of signals applied to change the state of display **10** in accordance with Figs. 4 and 5. In the two examples, a flash pulse **100** is applied to display **10** either slightly before (Example 1) or at the start of development pulse **130** (Example 2). Development pulse **130** is an electrical field applied across cholesteric material in display **10**. Development pulse **130** in this case is a bipolar pulse having a voltage corresponding to drive modes found in Fig. 4 and Fig. 5. In Example 1, flash pulse **100** occurs before the application of development pulse **130**. Flash pulse **100** is short because xenon flash lamps emit light in under one millisecond. A thermal pulse **105** occurs as a result of the application of light from the xenon flash lamp. In example 2, flash pulse **100** occurs at the start of development pulse **130**. The flash pulse **100** may also occur

near the end of the development pulse **130**, however the optimal amplitude of the development pulse will be different than the optimal amplitude when the flash pulse occurs at the start of the development pulse. Images can be formed using only energy from the flash unit, however image quality is significantly improved by the application of an electrical field at elevated temperatures experienced during thermal pulse **105**.

Experiments were performed to investigate optimum parameters for development pulse **130**. A transparency mask **54** was used to determine optimum parameters. Mask **54** had transmissive areas with over 90% transmission across all wavelengths and blocking areas with less than 10% transmission across all wavelengths. Experiments indicated that the acceptable levels of contrast in display **10** using such masks can be achieved when development pulse **130** was between 5 and 100 milliseconds. It was also determined that flash pulse **100** could occur within 5 to 10 milliseconds from the start of development pulse **130** (t2-t0). The time required for energy deposited at dark layer **35** to raise the temperature in cholesteric material **30** will be referred to herein as the delay time. When mask **54** was replaced with the STN display, the STN display created poor images on display **10** due to poor energy modulation. It became apparent therefore that an improved writing scheme using a combination of flash energy and electrical fields was needed, and was particularly needed for use with masks having low modulation capability such as STN displays.

Fig. 11A is a waveform diagram useful in describing one embodiment of the improved writing method of the present invention using a two phase drive scheme. A first non zero voltage pulse **120** is applied to the display. Immediately thereafter, a second non zero voltage pulse **110** having a different voltage from the first voltage pulse **120** is applied to the display. A flash light pulse **100** can be applied prior to or during the first voltage pulse **120**, or during the second voltage pulse **110**. By using two non zero voltage pulses, the state of the liquid crystal can be more accurately controlled before, during and/or after the flash pulse.

Experiments showed that good results were achieved when the second voltage pulse (e.g. 120V) was greater than the first (e.g. 10V for 40 milliseconds) and the duration of the second voltage pulse was less than two milliseconds and could be as short as 0.1 milliseconds. The areas receiving greater light were switched to a planar state (reflective state), while the areas receiving smaller light were converted to a focal conic state (transparent state). This image has been referred to as a positive image.

Good results were also achieved when the first voltage pulse (120V for 100ms) was greater than the second voltage (10V for 20ms). The areas receiving more light changed to a focal conic state (transparent state), while the areas receiving less light changed to a planar state (reflective state). The flash occurs during the second voltage. This image has been referred as a negative image.

Fig. 11B shows that the first and second voltages can be generated by bipolar waveforms that have the same amplitudes and different duty cycles **141, 142**, or that have different amplitudes and 100% duty cycles **143, 144.**

Fig. 12A is a waveform diagram useful in describing an alternative embodiment of the improved writing method of the present invention using a three phase drive scheme. A third voltage pulse **122** is added between the first **120** and second **110** voltages. In one example, the first voltage pulse **120** drives cholesteric material in display **10** into the focal-conic state.

In the three phase drive scheme, a first voltage pulse **120** is applied at t2, prior to application of flash pulse **100**. Flash pulse **100** is applied at time t0. A third voltage pulse **122** that functions as a holding field, is applied during the time period between the end of first preparation pulse **120** and the second voltage (referred as excitation pulse) **110** to hold the cholesteric material in a state under an electric field. Excitation pulse **110** is applied after third voltage pulse **122**. The application of a series of voltages before and during the flash pulse creates good images using STN or similar masks having poor flash modulation quality. Experiments were performed to find an optimized voltage sequence. Best

operation using this drive scheme with displays of the preferred embodiment had the parameters shown in Table 1 below.

Table 1

	First Voltage	**Third Voltage**	**Second (Excitation) Voltage**
Voltage	60V	20V	120V
Period	1ms	1ms	0.1-0.5 ms
Cycles	400	4	1

Referring to Fig. 12B, the third voltage **122** can be zero voltage and have a duration sufficiently long, so that the flash **100** occurs well (e.g. more than 1 second) after the end of the first voltage **120**. The first voltage **120** sets the liquid crystal into a proper initial state, in one example, being the focal conic state. At an initial time (t0), flash pulse **100** is applied across a masking STN displays. Application of flash energy creates thermal pulse **105**. A short time delay (t0 to t1) is provided before applying a short, high intensity excitation pulse **110** to display **10**. Time delay t1-t0 permits energy deposited at dark layer **35** to raise the temperature of cholesteric layer **30**. High quality images can be written using low energy modulating displays such as the Tianma unit as a masking display **94**. Without wanting to be bound by the physical mechanism behind the writing, it is believed that excitation voltage **110** is applied only during the highest temperature thermal pulse **105.** Eliminating electrical excitation during the cool down times of thermal pulse **105** improves responsiveness of display **10** to variation in applied energy. Excitation pulse **110** is timed to apply an electrical field at peak temperature, and omits electrical fields as cholesteric material **30** cools down

Experiments were performed to optimize parameters under these conditions. The aforementioned STN display was used as the optical mask. It was found for experimental displays **10** formed in accordance with one embodiment, a time delay of approximately 4 milliseconds was optimum before the application of excitation pulse **110**. Excitation pulse **110** was preferably applied for a time period of 0.20 to 0.70 millisecond at voltages between 90 and

120 volts. Experiments used to generate data in Fig. 4 and Fig 5. used a high contrast mask **54** and applied development pulse **130** for a time period corresponding to the entire duration of thermal pulse **105**. The short, high voltage pulses of excitation pulse **110** applied during the peak temperature of thermal pulse **105** created high contrast, high brightness images using STN displays poorer energy modulation than mask **54**. The image quality of STN masked images was improved over drive schemes using low voltage, long time period electrical drive schemes referenced in Fig. 4 and Fig. 5.

Fig. 13 is a representation of states of liquid crystals written in accordance with the present invention. In the invention, liquid crystal material is first written into the focal conic state (FC). A short, high voltage excitation pulse **100** replaces development pulse **130**. During the tie corresponding to maximum temperature, excitation pulse **110** converts focal conic liquid crystal into a transient homeotropic (H) state. After thermal pulse **105**, material in the homeotropic state changes into reflective planar liquid crystal. At slightly lower temperatures, corresponding to lower applied energy through masking display **94**, focal conic material remains in the focal conic state. This drive method provides good image quality with slight differences in energy levels, as provided by simple STN displays. It can also be applicable in other systems providing greater differences in energy. Applying a sequence of drive voltages initializes cholesteric material and electrically maintains cholesteric material in the initialized state during the writing process.

Fig. 14 is a waveform diagram useful in describing an alternative embodiment of the improved writing method of the present invention using a four phase drive scheme. A fourth voltage pulse **124** is added between the first **120** and third **122** voltages. The combination of the first **120** and fourth **124** voltages allows more control of liquid crystal states before the flash **110** occurs. In one example, the first voltage **120** is a high voltage that aligns cholesteric material into the homeotropic state. A lower voltage **124** is then applied to convert the material into the focal conic state. It is believed that the sequence of voltages, which

switch the cholesteric material first into the homeotropic and then the focal conic state, drives cholesteric material into a state that is more suitable for subsequent voltages **122** and **110** and flash to convert the cholesteric liquid crystal material into two optically distinct states depending on the amount of light that the material receives. Display **10** written using this procedure had good contrast. The application of a series of voltages before and during the flash pulse drives cholesteric material into preferred states and maintains those states. Such drive schemes create good images using STN or similar masks having poor flash-modulation quality. Best operation using this drive scheme with displays of the preferred embodiment had the parameters shown in Table 2.

Table 2

	First Voltage	Fourth Voltage	Third Voltage	Second (Excitation) Voltage
Voltage	120V	55V	20V	120V
Period	1ms	1ms	12ms	0.2ms
Cycles	100	45	1	1

A series of fields having varying voltage and time can be applied to prepare the cholesteric material prior to and during flash pulse **100** and excitation pulse **110**. In general, these pulse trains convert the cholesteric material into the focal conic state and are followed by a short, high voltage pulse to convert cholesteric material from the focal conic to the transient homeotropic to form a planar texture. A series of pulses having various voltage and duration can be applied prior to the flash and between the flash and excitation pulse to improves display quality. These schemes are all useful in writing displays **10** with STN displays having poor light modulation.

Fig. 15 is a waveform diagram useful in describing an embodiment of the improved writing method of the present invention using a five phase drive scheme. A fifth voltage pulse **126** is added between the first **120** and fourth **124** voltages. The combination of the first **120**, fifth **126**, and fourth **124** voltages allows further control of liquid crystal states before the flash **100** occurs. In one

example, the first voltage **120** is a high voltage that aligns cholesteric material into the homeotropic state. A lower and short voltage **126** is then applied to convert the material into a transient planar state. A medium voltage **124** is then applied to convert the material into the focal conic state. At the end of the fourth voltage **124**, it is believed that the cholesteric material is in a dynamic evolutional process, that will evolve to a stable focal conic state if a sufficiently long time is provided. This dynamic process is more suitable for subsequent voltages **122** and **110** and flash to convert the cholesteric liquid crystal material into two optically distinct states depending on the amount of light that the material receives. Display **10** written using this procedure had good contrast. The application of a series of voltages before and during the flash pulse drives cholesteric material into preferred states and maintains those states. Such drive schemes create good images using STN or similar masks having poor flash-modulation quality.

With various combinations of the first **120**, fifth **126** and fourth **124** voltages as known in the art, and the end of the fourth voltage, the cholesteric liquid crystal material can be in a stable planar or focal conic or combination of planar and focal conic state, or in a known dynamic process such as from the homeotropic to focal conic state, or from the homeotropic to planar state, or from the transient planar to focal conic state, or from planar to focal conic state.

The flash **100** can also occur during the fourth and fifth voltages. More voltage phases allow further improvement at a higher cost. In three phase, four phase, and five phase drive waveforms, the first, second, third, fourth, and fifth voltages can be generated by bipolar waveforms that have the same amplitudes and different duty cycles, or that have the different amplitudes and 100% duty cycle.

Fig. 16 is a spectra plot of the reflectance of a display written in accordance with the present invention. A display made in accordance with the current embodiment was written using a high intensity xenon flash, the aforementioned STN display and a multi-phase drive scheme. The written image had a peak reflection of 24% in the planar state (P) and 3.5% reflection in the

focal-conic (FC) state, with a contrast ratio of 6.8. Displays **10** written with such optical characteristics have useful application in commercial systems.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

10	display
15	display substrate
20	first transparent conductor
20'	exposed first conductor
22	first conductor cover
30	cholesteric layer
35	dark layer
40	second conductor
50	electrodes
52	flash
54	mask
60	incident light
62	reflected light
72	planar liquid crystal
74	focal conic liquid crystal
80	object
82	contacts
90	writer
91	power supply
92	flash capacitor
93	display drive
94	masking display
95	controller
96	trigger circuit
100	flash pulse
105	thermal pulse
110	second (excitation) voltage pulse
120	first voltage pulse
122	third voltage pulse
124	fourth voltage pulse
126	fifth voltage pulse
130	development pulse
141-144	bipolar waveforms